

Pierce & Reeder

The Construction of an induction motor

Electrical Engineering

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THE CONSTRUCTION OF AN INDUCTION
MOTOR

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BY

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AND
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THESIS

FOR

DEGREE OF BACHELOR OF SCIENCE

IN

ELECTRICAL ENGINEERING

COLLEGE OF ENGINEERING

UNIVERSITY OF ILLINOIS

PRESENTED JUNE 1910

UNIVERSITY OF ILLINOIS

June 1 19010

THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

DONALD ALFRED PIERCE and CLAUDE HAZLETT REEDER

ENTITLED THE CONSTRUCTION OF AN INDUCTION MOTOR

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE

DEGREE OF Bachelor of Science in Electrical Engineering

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THE CONSTRUCTION

OF AN

INDUCTION MOTOR

Believing that the construction of an induction motor would lead to a detailed study of the subject, and that the complete machine would add useful experimental value to the laboratory this subject was considered as a worthy one.

The subject may be conveniently divided into two parts, one of design and one of construction. In the limited time for such work the construction has had to be given greater attention, although it has taken considerable time and careful thought for each part. It was intended at first to start the construction early in the school year but owing to delays the material did not arrive until in February when only a short time was left.

DESIGN.

The stampings for this motor were obtained from the General Electric Company because of the difficulty in getting them in the correct shape without special machinery, if the raw material had been

purchased. The frame, spider, windings, bearings and other parts of the motor were designed to conform to the stampings. A suitable frame was constructed to hold the quarter circle laminations and a spider was made for the rotor. As the rating of the motor depends upon the type of windings, a winding was selected which could be used efficiently in the laboratory with this machine.

The stator has 72 open slots in which two half coils are placed in one slot. Each coil consists of 9 turns of two No. 14 double cotton covered wires. The throw of the coil is 1 and 13. There is 50 lbs. of copper in the stator winding. The resistance per phase(3 phase) is .82 ohms when connected in a single circuit. The resistance will vary inversely with the ^{square of the} number of circuits connected in parallel. The reactance as calculated from the shape of the slot and other conditions is 3.66 ohms. At full load the current density will be 550 circular mils per ampere.

By a few changes in the connections the machine may be made to operate on a number of different voltages. As calculated the machine may be rated at 440 volts with a Y single circuit connection. Other possibilities of voltages are given below.

(Note) - A sketch with directions for making the various connections is included in this thesis on page 8 .

The rotor of this machine is of the squirrel cage type, there are 59 bars $1/4"$ x $5/16"$ and $8-1/2"$ long placed on edge in the slots. The rotor slots are nearly closed. The end rings are made of soft drawn copper $1/4"$ x $1-1/2"$ in section. The rotor equivalent resistance as computed is .8 ohms and the equivalent reactance is 1.91 ohms. In all there is 25 lbs. of copper in the rotor.

CONSTRUCTION.

Before the mechanical construction of the motor began it was necessary to make the patterns. These were made by the authors. As soon as each pattern was completed it was taken to the University foundry where all the castings were made. The machine shop was utilized in finishing the castings which were, when completed, assembled so that the windings could be put in place.

FRAME.

A pattern was made for the frame. It consisted of two rings which were joined by inwardly projecting ribs or lugs. The core consists of numerous segments punched from especially treated thin sheet steel. These laminations are dovetailed in each of the lugs to prevent all circular motion of the sections. Iron end rings forced together and keyed to the iron frame prevent lateral motion. The slots which were made in the lugs also enabled the punched steel to line up so that the coils could be easily entered.

When the motor is operating, air can circulate between the end rings and the laminations through the wind vanes. The tips of these vanes also serve to hold the teeth in the required place. The back of the laminations are open to the air except where the lugs hold them in place.

The foot was made in a separate piece on account of the machine in which the frame was turned being too small to allow any projections.

BEARING BRACKETS.

Both bearing brackets are separable from the frame and as this machine is intended for use in the laboratory the brackets have been left open so that the connections may be inspected or varied easily. Each bracket is fastened to the frame by cap screws.

ROTOR.

The secondary, or rotor, is of the slotted drum type. The core is built up of steel punchings pressed and keyed to a cast iron spider. The laminations are held together by cast iron end rings, each ring being separated from the steel punchings by wind vanes. The vanes also serve to hold up the laminations the same as in the stator.

SHAFT.

The shaft is turned from axle steel. It is provided with a key way for the spider hub and also one for the pulley, and with grooves such that any oil will not run from the bearing to the rotor.

BEARINGS.

The bearings consist of brass bushings pressed into the housings of the bearing brackets. Each is equipped with two rings that distribute the oil from the oil wells and keep the bearings lubricated.

The coils for the stator were wound from two reels onto a straight arbor made for this job. After winding they were spread on an improvised apparatus to the diamond shape as shown in the photograph on page 17. The coils were next insulated. Empire cloth was half lapped over the parts of the coil out of the slot. The empire was covered with linen tape as a protection. In the slots the coils are insulated from the iron by a sandwich of two pieces of press board and one of empire cloth. Linen tape was used to connect the end of the tube formed by the slot insulation with the coil insulation, so that the wires are completely covered. This method of coil insulation makes a mechanically protected coil as well as a sound electrical construction. The method of placing the coils in the slots is too intricate to describe briefly and so the pictures on page 17 have been inserted to give an idea as to how the work was done. The coils are held in the slot by fiber wedges. The price of wedges ready made was so high that it was decided by the authors to make them up from raw material. The sheet of fiber was sawed in strips in the band saw and the edges finished in the shaper.

The rotor as has been stated already is of the squirrel cage type. The bars were made from stock of the proper diameter. A hole was drilled in the end of each bar to receive a rivet from the end rings. The slots were lined with strips of press board to make the bars fit snug. Wooden wedges were driven into the top of the slot to further secure the bars. The end rings were formed from straight pieces of copper. The joint in the ring is a spliced butt joint, rivited and sweat ed. The rings are fastened securely to the rotor frame to prevent any possible play. The bars as has been suggested were riveted to the rings. The electrical contact was further secured by thorough sweating. The successful operation of a motor

depends somewhat upon the balance of the rotating parts. Care was taken to mount the end rings in such a position that the splices balanced each other and also made up a slight unbalancing in the rest of the rotor.

REMARKS.

From the brevity of this text it might be assumed that no difficulties were encountered and that everything went smoothly. However such was not the case. In the shops where the work was done the underclassmen were taking instruction and were given preference quite often in the use of machines. Then every different piece had to be rigged for specially and the machines always had to be adjusted. The troubles extended from the more important considerations down to the smallest details. Such little details as a loose belt, an untrue lathe or falling sand in a bracket would give opportunity for inaccurate work and required a great deal of unproductive time.

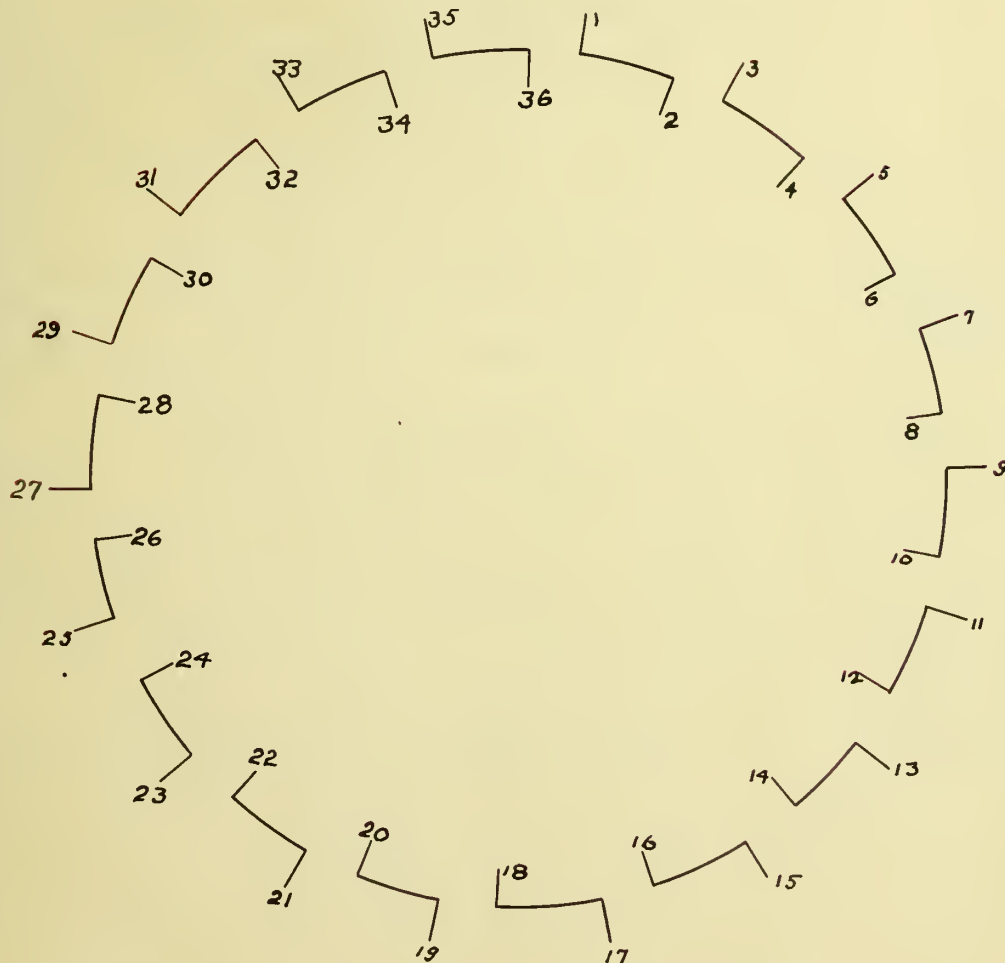
Now that the machine is completed we can see many places where it might have been made differently for the better. The performance curves as they were calculated show a low power factor. This is due to the open slots and low speed. Higher speed or closed slots would greatly benefit this defect. The maximum theoretical out put is low, due also to the open slots. The curves and calculations for the motor performance give an idea of what we expect the machine to do under actual test.

SUMMARY OF MOTOR PARTS.

Stator frame and foot.	245 #
Stator clamping rings.	25
Brackets, 60# each.	120
Potor not wound with shaft.	147
Copper stator.	50
copper rotor.	<u>35</u>
Total.	612 #

R. P. M.	1200
Rotor resistance.	.8 ohms.
Stator resistance.	.82
Rotor reactance.	1.91
Stator reactance.	3.66

*Connecting Diagram
for
3-phase Induction Motor.*



Each section represents a group of four coils in series. Numbers refer to leads of each group.

Directions for Reconnecting

(3 Phase, 6 Poles, 60v)

The coils are grouped in 18 groups of 4 coils each, with the group terminals or leads numbered as in the Diagram - Page 8 .

By connecting the group terminals as indicated on the following Pages, any desired connection with its corresponding voltage rating, may be made.

The three Machine terminals or Leads are designated as, A, B, and C.

1 Circuit Y Connection

6 Poles - 60~ - 440 Volts

Leads, H, 23 - B, 19 - C, 15.

Neutral 21 - 17 - 13

Connect other terminals as follows,

20	to	26
22		28
24		30
25		31
		33
27		35
29		2
32		
34		4
36		6
1		7
3		9
5		11
8		14
10		16
12		18

Note For further information See Diagram-Page 8

2 Circuit Y, Connection

6 Poles - 60~ - 220 Volts.

Leads - A, 23+6 - B, 19+2 - C, 15+34

Neutral - 21, 17, 13, 32, 36, 4.

Connect other terminals as follows,

20	to	26
22		28
24		30
25		31
27		33
29		35
1		7
3		9
5		11
8		14
10		16
12		18

Note. For further information see Diagram - Page 8

3 Circuit Y Connection

6 Poles - 60~ - 147 Volts

Leads - A, 21, 33 + 9 - B, 25, 1 + 13 - C, 29, 5 + 17.

Neutral - 19, 23, 27, 31, 35, 3, 7, 11, 15.

Connect other terminals as follows

20 to 26

22 28

24 30

32 2

34 4

36 6

8 14

10 16

12 18

Note. For further information See Diagram - Page 8

6 Circuit Y Connection

6 Poles - 60 ~ - 73.5 Volts.

Leads-	A, 4 -	B, 5 -	C, 8
	9	12	13
	16	17	20
	21	24	25
	28	29	32
	33	36	1

Neutral, 2, 3, 6, 7, 10, 11, 14, 15, 18, 19, 22, 23, 26, 27,

30, 31, 34, 35.

Note For further information see Diagram Page 8

All group terminals connect directly to the leads or the neutral.

Δ Connections

6 Poles 60 v.

1 Circuit ²
254 Volts

Leads, A, 23, 21 - B, 19, 17 - C, 15, 13.

Connect other terminals as in, Y, 1 Connection.

2 Circuit 127 Volts

Leads, A, 23, 21 - B, 19, 17 - C, 15, 13

6, 4 2, 36 34, 32

Connect other terminals as in, Y2 Connection.

3 Circuit 85 Volts

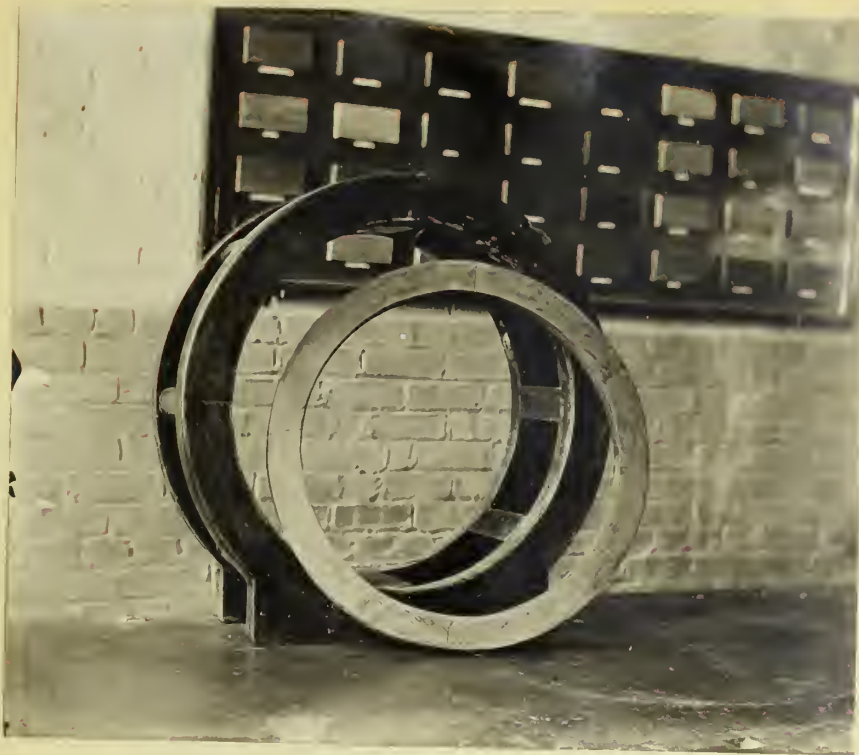
Leads, A, 23, 21 - B, 25, 27 - C, 29, 31

33, 35 1, 3 5, 7

9, 11 13, 15 17, 19

Note For further information See Diagram Page 8

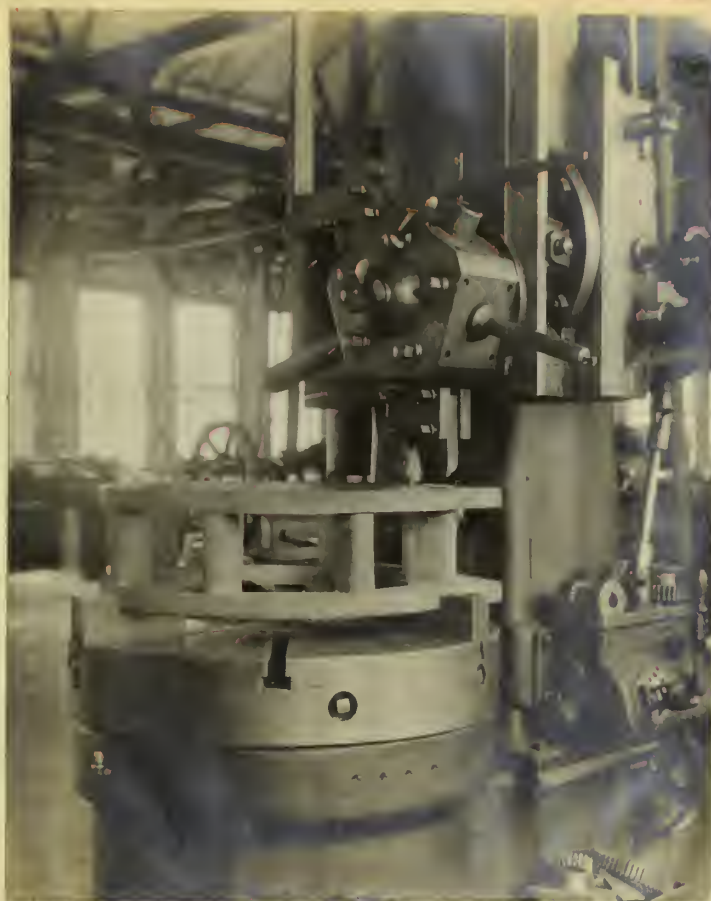




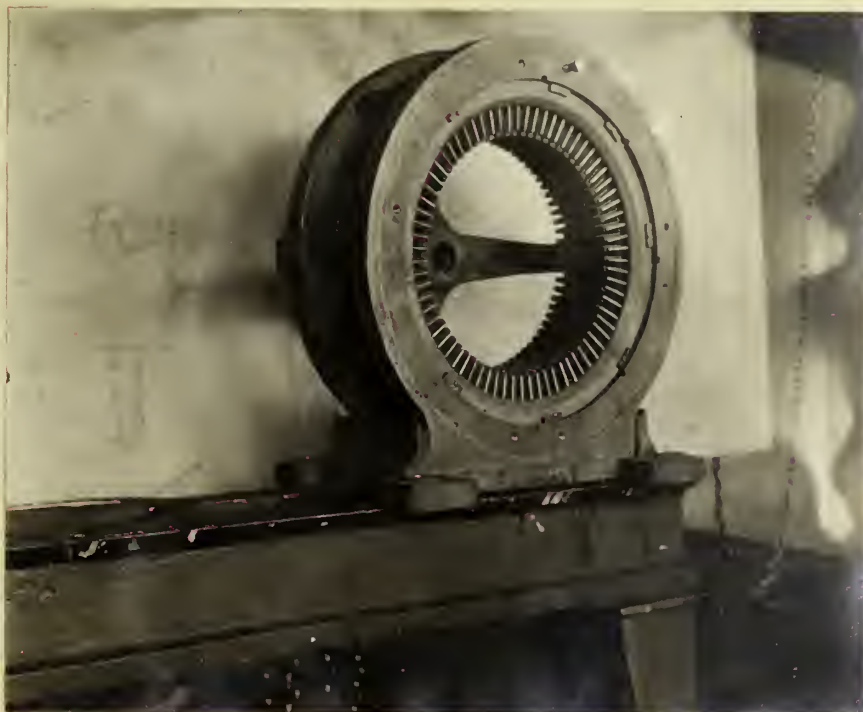
Stator Patterns



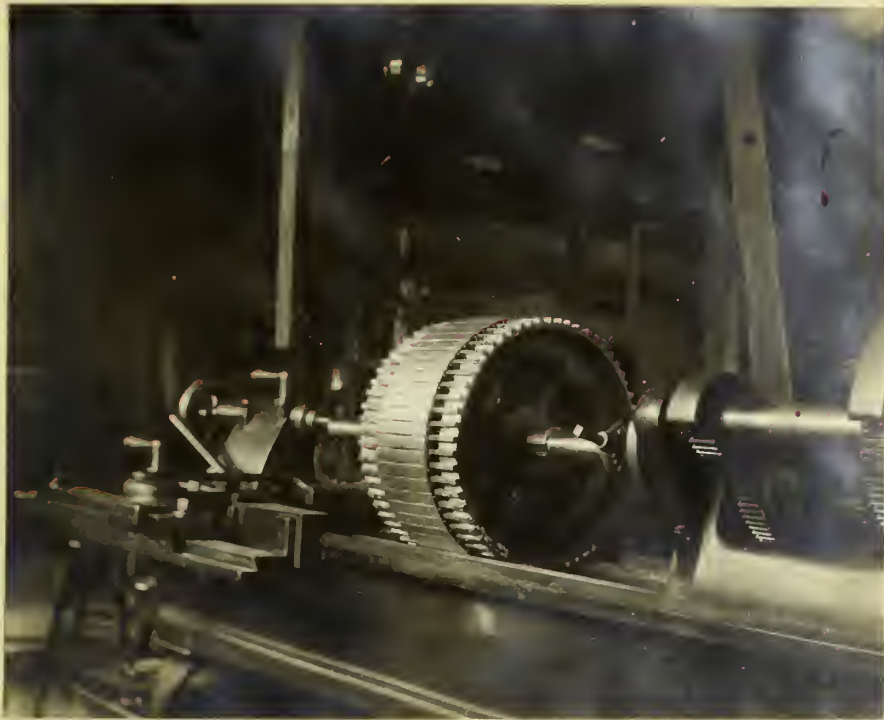
Bearing Bracket Mould



Stator Frame in Boring Mill.



Stator,



Rotor in Lathe



Coils and Stator Core.



The following calculated results were obtained by the use of equations derived by Steinmetz in his Elements of Electrical Engineering, page 357, edition 3.

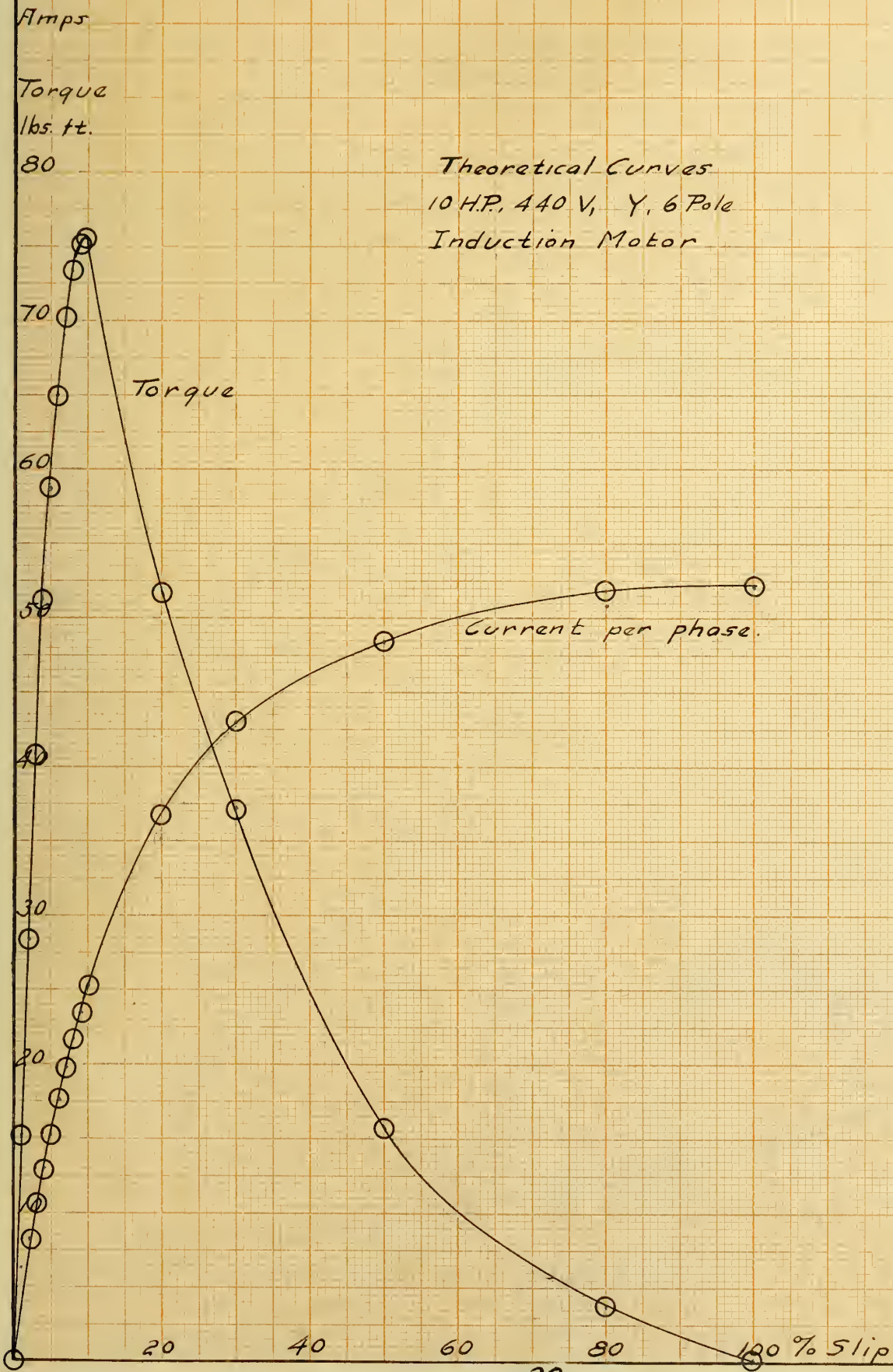
r_1 Secondary resistance .8
 r_o Primary resistance .82
 x_1 Secondary reactance 1.91
 x_o Primary reactance 3.66

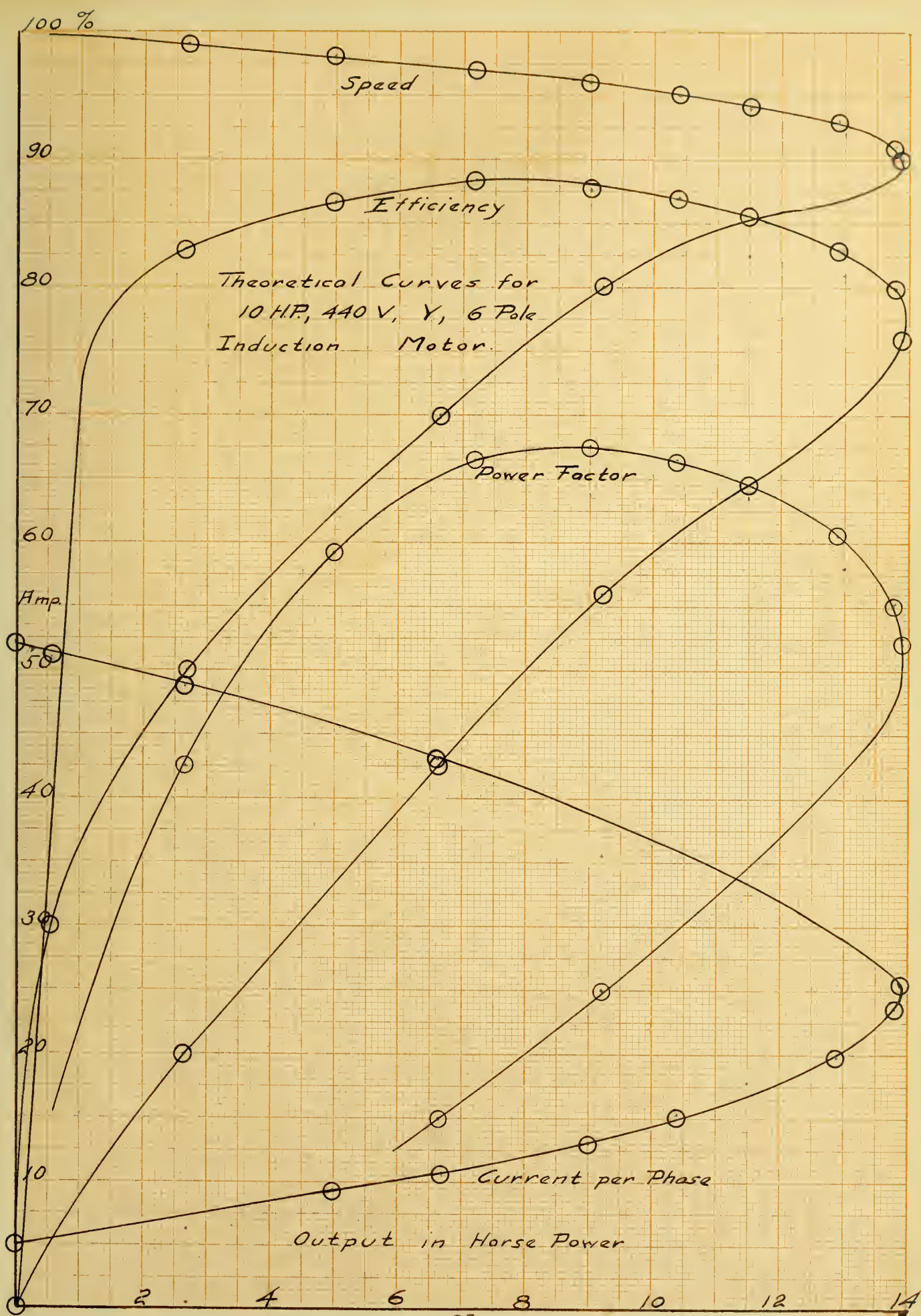
$r_1 s$	sx_1	$\frac{r_1^2 s^2}{sx_1^2}$	$r_1^2 + sx_1^2$	$\frac{r_1 s}{r_1^2 + (sx_1)^2}$	$\frac{x_1^2 s^2}{r_1^2 + (sx_1)^2}$	Slip.
.00	0	0	.64	$\frac{r_1 s}{a_1}$	$\frac{x_1^2 s^2}{a_2}$	0
.008	.0191	.000365	.640365	.0125	.00057	.01
.016	.0382	.00146	.64146	.02495	.00228	.02
.024	.0574	.00033	.6433	.0374	.00514	.03
.032	.0765	.00585	.64585	.0495	.00905	.04
.040	.0955	.0091	.6491	.0618	.014	.05
.048	.1145	.01315	.65315	.0735	.0218	.06
.056	.1337	.0179	.6579	.085	.0272	.07
.064	.153	.0234	.6634	.0966	.0353	.08
.072	.172	.0296	.6696	.1075	.0442	.09
.08	.191	.0365	.6765	.1184	.054	.10
.16	.382	.146	.76	.2035	.186	.2
.24	.574	.33	.97	.2475	.34	.3
.4	.955	.91	1.55	.258	.587	.5
.64	1.528	2.34	2.98	.215	.785	.8
.8	1.91	3.65	4.29	.186	.85	1.

$g_0 + a_1 b_0 + a_2 \sqrt{b_1^2 + b_2^2}$	$1 + b_1 r_0 + b_2 x_0$	$r_0 b_2 - b_1 x_0$	$\sqrt{c_1^2 + c_2^2}$	Slip.		
b_1	b_2	c_1	c_2			
.00114	.0228	.0228	1. 084	.0148	1.085	0
.01364	.02337	.0271	1.096	-.0295	1.1	.01
.02609	.02508	.0362	1.116	-.075	1.117	.02
.03854	.0279	.0475	1.133	-.1181	1.14	.03
.05064	.0319	.0596	1.157	-. 1589	1.165	.04
.06294	.0368	.0728	1.185	-.1998	1.21	.05
.07464	.0446	.0866	1.224	-.2364	1.245	.06
.08614	.05	.1	1.253	-.274	1.28	.07
.09774	.0581	.1136	1.292	-.3103	1.33	.08
.10864	.067	.1273	1.333	-.342	1.371	.09
.11954	.0768	.1421	1.377	-.3732	1.43	.10
.20464	.2088	.2922	1.932	-.5758	2.01	.2
.24864	.3628	.44	2.534	-.618	2.60	.3
.25914	.6098	.66	3.442	-.446	3.47	.5
.21614	.8078	.821	4.136	-.127	4.12	.8
.18714	.8728	.89	4.340	.03	4.34	1.

$\frac{E_0}{\sqrt{c_1^2 + c_2^2}}$ e	$e(b_1 + jb_2)$ I_0	$b_1c_1 + b_2c_2$ D	Torque watts $e^2 a_1$	Power watts. T(1-s)	P-f P-30	Slips.
234	5.14	.0016	0	0	-30	0
230	6.21	.0144	670	663	633	.01
227	8.22	.0275	1285	1260	1230	.02
223	10.6	.0404	1865	1811	1781	.03
218	13.	.0538	2360	2271	2231	.04
210	15.25	.0669	2740	2600	2570	.05
204	17.6	.081	3060	2800	2850	.06
198	19.8	.094	3340	3110	3080	.07
191	21.8	.1085	3530	3249	3219	.08
185	23.5	.121	3680	3340	3310	.09
177	25.2	.1405	3700	3335	3315	.1
121	35.3	.275	2980	280	2250	.2
97.8	43.	.50	2360	1650	1620	.3
73.2	48.3	.62	1387	694	664	.5
61.6	50.8	.8	821	164	134	.8
58.6	52.	.856	640	0	0	1.

$D e^2$ P_o Watts.	$I_o E_o$	$\frac{P - f}{P_o}$ Eff.	$\frac{P - f}{E_o I_o}$ P.F.	$(P - f).00403$ H.P.	$T \times .0226$ Torque ft. lb.	Slip.
862	1305	.348	.023	- .121	0	0
764	1575	.83	.425	2.68	15.12	.01
1418	2082	.866	.592	4.96	28.4	.02
2017	2685	.884	.665	7.2	40.75	.03
2555	3300	.875	.675	9.	51.	.04
2958	3875	.871	.665	10.37	58.7	.05
3470	4482	.855	.635	11.5	65.	.06
3700	5040	.83	.612	12.9	70.3	.07
3970	5540	.825	.58	13.5	73.4	.08
4150	5975	.80	.55	13.8	75.3	.09
4400	6400	.86	.52	13.9	75.3	.1
4720	6950	.56	.25	9.2	51.5	.2
3810	10920	.425	.15	6.63	37.2	.3
3330	12250	.199	.05	2.68	15.7	.5
3050	12900	.044	.01	.544	3.70	.8
2940	13200	0		0	0	1.









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